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Effect of Thermal Shock on Predator Avoidance by Larvae of Two Fish Species

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ABSTRACT

Larvae of two fish species, *Menidia menidia* and *Paralichthys dentatus*, were subjected to a 15-min thermal shock of 10 C above acclimation temperature, returned to acclimation temperature, and exposed to a predator, *Fundulus majalis*. Four- and six-week-old *M. menidia* were significantly more vulnerable to predation after being shocked than control larvae, but younger larvae were not. Shocked larvae of *P. dentatus* were less susceptible to predation than control larvae.

Increased vulnerability to predation of a number of juvenile fish species has been demonstrated following sublethal thermal shock (Coutant 1973; Sylvester 1972; Yocum and Edsall 1974). However, most juvenile and adult fish are thought to have the swimming capacity to avoid the thermal plume of a power plant (Committee on Water Quality Criteria 1972). Weakly swimming ichthyoplankton have a greater potential to intercept a thermal discharge plume (Brewer 1976). Therefore, the present study was undertaken to extend knowledge of sublethal effects of thermal shock on vulnerability to predation of larval fish.

METHODS

Larvae of *Menidia menidia* (newly hatched to 6 wk old) and *Paralichthys dentatus* (newly hatched) were chosen as prey. Larval *M. menidia* normally occur in estuarine areas of southern New England during the warm summer months. They are strong swimmers and have good escape abilities at hatching. Larvae of *P. dentatus* have weak swimming ability and develop during the cool late-fall months. Larvae of both prey species were reared at Narragansett Bay water temperatures (*M. menidia* 19.0–20.0 C; *P. dentatus* 14.5–15.5 C) from eggs spawned at this laboratory.

The predator, *Fundulus majalis*, is a common carnivorous estuarine species along the Atlantic coast from Cape Cod to Florida (Bigelow and Schroeder 1953). *Fundulus majalis* (6–8 cm total length) were captured by seine from Bissel Cove, Narragansett Bay, Rhode Island, and maintained in large flow-through holding tanks under a 10-h light:14-h dark photoperiod. Each predator was used only once in a test. The predator was placed into a test tank 48 h prior to an experiment and deprived of food during that period.

Test tanks were polypropylene tubs 30 cm diameter times 12.5 cm deep with clear Plexiglas bottoms. All activities in the tank were viewed from below. Illumination was 1,000 lux at water surface.

A test was conducted by introducing shocked or control larvae into the experimental tank in groups of 10 at intervals of 6 min. Attacks, captures, and escapes were recorded. A continuous flow (400 ml/min) of bay seawater was maintained to control temperature in the test tanks. All tests were run at approximately the same time of day (1300 to 1500 h). Satiation points of the predator for each group of prey were estimated in preliminary tests, and these numbers of larvae were used throughout subsequent tests.

Groups of 10 larval *M. menidia* were maintained at 20.5 ± 0.7 C in perforated polypropylene beakers 4 h prior to a test. During shock tests, beakers were transferred at 6-min intervals to seawater heated to the shock temperature of 30.0 ± 0.6 C; $\Delta T = 9.7 \pm 0.7$ C. Temperature equilibration occurred within 1 min. After a 15-min exposure at 30 C, each beaker was cooled in a water table for 5 min, then introduced to the predation tank via the inflowing seawater. For control tests, beakers containing larvae were held in a seawater table at 20.5 ± 0.7 C, and introduced to the predation

TABLE 1.—*Pooled data for each age and size (total length) category, giving mean and one standard deviation in parentheses. S = shocked group (15 min duration:* M. menidia *ΔT = 9.7 C;* P. dentatus *ΔT = 10.1 C), C = control group,* N = *number of tests.* *P < *0.05;* **P < *0.01: Wilcoxon ranked sum test of shocked vs. control means.*

Group	Number of attacks		Number of escapes		Number of captures		No. escapes per no. attacks		Number introduced	
	C	S	C	S	C	S	C	S	C	S
M. menidia										
1–3 day; 4 ± 0.3 mm; N = 3 C, 3 S; 50 larvae/test	63.0 (7.6)	64.8 (11.0)	17.0 (4.6)	17.3 (12.0)	46.0 (3.5)	47.3 (1.5)	0.270 (0.043)	0.268 (0.139)	150	150
2 wk; 9.8 ± 2.9 mm; N = 5 C, 4 S; 30 larvae/test	61.4 (9.7)	53.0 (19.5)	33.0 (8.6)	26.0 (16.5)	28.4 (1.1)	27.0 (3.2)	0.537 (0.056)	0.491 (0.131)	150	120
4 wk; 12.2 ± 1.8 mm; N = 14 C, 20 S; 30 larvae/test	74.3 (13.1)	60.4** (13.1)	45.6 (12.9)	32.4** (12.1)	28.7 (1.4)	28.0 (2.7)	0.613 (0.067)	0.536** (0.089)	420	600
6 wk; 23.5 ± 0.7 mm; N = 8 C, 8 S; 20 larvae/test	35.5 (8.9)	25.8** (7.1)	25.4 (9.3)	15.3** (6.3)	10.1 (1.5)	10.5 (1.9)	0.715 (0.089)	0.592** (0.097)	160	160
P. dentatus										
1–3 day; 4 ± 0.2 mm; N = 5 C, 5 S; 50 larvae/test	56.8 (2.9)	66.0* (8.6)	8.4 (2.5)	17.8** (6.3)	48.4 (1.3)	48.2 (2.4)	0.148 (0.038)	0.270** (0.061)	249	240

tank in groups of 10 at 6-min intervals. In the present study, shock regimes used include a shock up and a shock down. Evaluation of independent effects of the two shocks is precluded by this design (Beitinger 1974; Coutant 1973).

Shocked larvae of *P. dentatus* were treated similarly, except they were not exposed to flowing water or to a cooling period between the 15-min thermal shock and introduction to the predation tank. Introduction to the predation tank was accomplished by siphon. Starting temperature for this species was 15.1 ± 0.8 C, and the shock temperature was 25.2 ± 0.8 C; ΔT = 10.1 ± 0.6 C.

Differences between shock and control tests in regard to number of predator attacks and captures, and prey escapes were analyzed for significance by the Wilcoxon distribution-free rank sum test (Hollander and Wolfe 1973).

RESULTS

Number of attacks, escapes and escape/attack ratios were significantly greater for control than for 4–6-wk-old shocked larvae of *M. menidia* (Table 1). Total number of captures of shocked and control prey did not differ significantly since predators were allowed to capture all larvae. Number of attacks and number of escapes per attack did not differ significantly between shocked and control larvae in 1–3-day-old and 2-wk-old *M. menidia*. Larvae of *M. menidia* did not lose equilibrium at any time during the tests, and no consistent behavioral differences could be observed between shocked and control individuals.

Shocked larvae of *P. dentatus* showed enhanced predation avoidance through increased escape response (Table 1). These larvae are normally quiescent, and swim only in intermittent short bursts over distances of 10–15 mm. If a swimming burst occurred during an attack, the prey usually escaped, and was not pursued by the predator. It is possible that thermal shock increased the frequency of swim burst activity in these larvae.

DISCUSSION

A 15-min exposure to the maximum shock temperatures used in these tests was not directly lethal to either species in preliminary tests. No visible differences in postexposure behavior of shocked and control larvae were noted in *M. menidia*. Austin et al. (1975) subjected larvae of *M. menidia* (1–4-day-old) to a 13-min thermal shock of 8 and 14 C above acclimation temperature of 17,

20, 25, and 30 C, and demonstrated that larvae reared at 17 and 20 C showed only minor stress at both thermal shock levels. My results with larvae of *M. menidia* (4 and 6 wk of age) indicate that a 15-min ΔT of 9.7 C above acclimation temperature of 20.5 C will significantly decrease the attack avoidance ability of these larvae in a predation situation. Such a change in ecological fitness may be considered adverse to population success (Herting and Witt 1967; Coutant 1973).

Young larval fish are often considered to be less tolerant of temperature changes than adults and juveniles (Brett 1970; deSylva 1969; Lewis 1965; Norris 1963). Newly hatched and 2-wk-old *M. menidia* did not show any significant differences in avoidance abilities between shocked and control groups, suggesting that these youngest larvae are not as sensitive to thermal shock as older larvae. Alternatively, statistically significant effects of thermal shock may have been masked by the high response variability and low number of tests run for these age-classes. However, prolarvae of *Leuresthes tenuis* and *L. sardina*, two Pacific atherinids, are reported to be more eurythermal than 30-day-old larvae (Reynolds and Thomson 1974; Reynolds et al. 1976).

Beitinger (1974) considers decreased activity a possible causal factor for increased predation vulnerability following thermal shock. He observed such activity decrease in juvenile *Lepomis macrochirus* following short-term thermal shock close to the incipient upper lethal temperature. In the present study, *M. menidia* experienced a 15-min exposure to 30.0 C, which approaches the 48-h LT50 (temperature killing 50% of the fish) of 30.7 C (21 C acclimation) for juvenile *M. menidia* (Hoff and Westman 1966). In contrast, the maximum temperature experienced by *P. dentatus* during the tests did not approach lethal thermal limits. The shock temperature of 25.2 C is 7 C below a reported critical thermal maximum of 32.2 C for postlarvae (size not given) at a 15 C acclimation temperature (Hoss et al. 1974). Escape responses were enhanced in *P. dentatus* following thermal shock, possibly due to increased sensory responsiveness or increased locomotory movements. Coutant (1973) suggested that short-term exposure to thermal shock temperatures far from lethal limits may actually be stimulatory, increasing escape chances. He estimated the threshold for increased predation vulnerability to occur in *S. gairdneri* at shock temperatures 2.5 C below 10–120 min LT50 values. Lack of LT50 data for larval *M. menidia* preclude a similar comparison within the present study.

Comparison of escape/attack ratios for *M. menidia* control larvae indicates a 50% increase in escape probability between newly hatched and 2-wk-old larvae. Subsequent increases in escape ability with larval growth over the ensuing 4 to 6 wk are relatively small. Neuromast innervation of the lateral-line canal system in *M. menidia* is completed in 9.0–11.0-mm larvae (Cahn et al. 1968). Mean total length for 2-wk-old *M. menidia* in this study was within this size range (9.8 ± 2.9 mm). Cahn and Shaw (1962, 1963) correlated maturation of the lateral-line canal system in larval *M. menidia* with initiation of parallel orientation in 8-mm larvae, and stabilized schooling in 11–14-mm larvae. Blaxter (1969) considers the free neuromast system in larvae to be of major importance in escape ability before full eye development. Perhaps the period of lateral-line canal innervation also increases ability of larvae to detect and avoid predators.

Yocum and Edsall (1974) suggest the technique of recording individual attacks, captures, and escapes is more sensitive than Coutant's technique of estimating instantaneous predation rates (Coutant 1973). Evaluation of predation sensitivity in the present design relative to thermal mortality levels awaits LT50 determinations for the larval stages used here. However, the present design is advantageous in that it provides a means to compare quantitatively interspecific and intraspecific (age-related) larval escape abilities. Similar techniques conceivably could be used to compare attack efficiencies among different predators using a standardized prey.

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